Spacecraft Pre-launch/Turnaround NDE needs at the Kennedy Space Center

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In-Space Non-Destructive Inspection Technology Workshop
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NDE included in NASA Roadmaps

Figure 1

Space Technology Roadmaps **STR • TABS**

TECHNOLOGY AREA BREAKDOWN STRUCTURE

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

CROSS-CUTTING

- Nondestructive Evaluation & Sensors
- Model-Based Certification & Sustainment Methods
- Loads and Environments

Table 22. *WBS # 2.5.1 NDE*

TECHNOLOGY PRODUCT Key Technology/Challenges	What It Enables	Current TRL/Status	Steps to TRL 6
a. NDE Complex Built-Up Structures Sensors and NDE methodologies for high-fidelity detection and characterization of flaws and degradation in complex built-up structures.	Assurance of the integrity of complex built-up structures.	TRL 2. Viable techniques for inspection of exposed surfaces and inspection following disassembly.	Sensors for prognostics and reconstruction techniques for data acquired from limited views of penetrating radiation 2013.
b. Computational NDE Predict the performance of NDE techniques on critical structures/materials.	Rapid development and certification of inspection techniques for complex composite configurations.	TRL 2-3. Ultrasonic simulations for homogenous material with inclusion of simplified flaws.	Validated simulations of ultrasonic inspections of composite structures/materials 2016.
c. Combined NDE and Structural Analysis Inclusion of accurate characterizations of damage in structural analysis routines.	Accurate assessment of the impact of damage on structural integrity.	TRL 1-2. Manual inclusion of NDE data into structural analysis routines.	Accurate residual life predictions based using data acquired from NDE 2020.
d. Autonomous Inspection Sensor and Autonomous Inspection (AI) controllers that ensure the proper performance and optimization of NDE systems without human interaction.	Performance of inspections in areas where a human interaction is either not possible, challenging, or too time consuming.	TRL 1-2. Development of systems with simplified human operations.	Sensors and AI systems for large area inspection 2023.
e. Real-time Comprehensive Diagnostics Methodologies of real-time diagnostics.	Integrity assurance of vehicles for long duration missions.	TRL 2-3. Impact and leak-detection systems for Shuttle orbiter and ISS.	Real-time diagnostic system for detection of fatigue and impact damage. 2025

Excerpt from the NESC Presentation on the "State of the NASA Nondestructive Evaluation (NDE) Discipline" *

- **NDE expertise in high demand across all NASA missions**
  - Challenge to provide sufficient expertise
  - Multi-Center cooperation key
    - e.g. NESC NDE TDT, NASA NDE Working Group (NNWG), Orbiter NDE Working Group (ONWG)
  - Reduced research capabilities and output lead to risk in meeting future mission requirements
- **Many mature NDE technologies – challenge applying them to complex aerospace materials and structures**
  - Composites, ceramics, TPS, multilayer, multi-functional structures, etc.
- **Interaction with other disciplines (materials, structures, etc.) present challenges**
  - NDE requirements, expectations, and need to consider NDE in the initial design
- **Structural Health Monitoring (SHM) is new frontier with great potential returns**
  - Critical for longer duration manned space missions

KSC NDE Vital to Overall NASA NDE Mission

- KSC NDE required to maintain KSC/CCAFS institutional facility
- KSC NDE required to support current customers (customers defined later slide)
- KSC NDE will be required for future customers
  - Beginning with Shuttle Program KSC has historical worked with operations centers (JSC, MSFC) and Research Centers (LaRC, GRC) to develop and implement advanced NDE procedures.
  - Current and future and NASA programs are dependant of KSC to maintain its current core and advanced capabilities

Where we are now: KSC NDE Laboratories

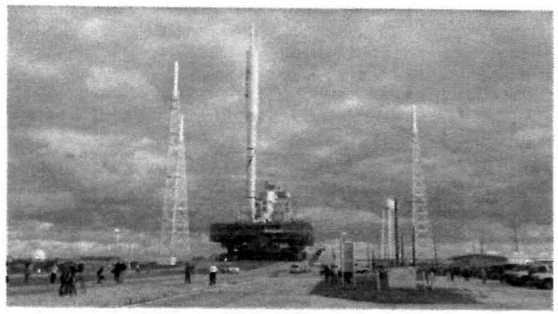
- **Institutional (ISC) NDE Primary Services**
  - **Provide Non-Destructive Testing and Evaluation for the Kennedy Space Center/Air Force Operational Programs and Facilities**
    - Examples include
      - Crane hooks
      - Lifting fixtures
      - Pressure vessels
    - Includes operational ground support equipment and flight vehicle hardware.
    - Provides 24/7 support launch site operations customers processing and launching rockets and payloads.
    - The Lab also develops new NDE techniques and equipment to improve evaluation capabilities.

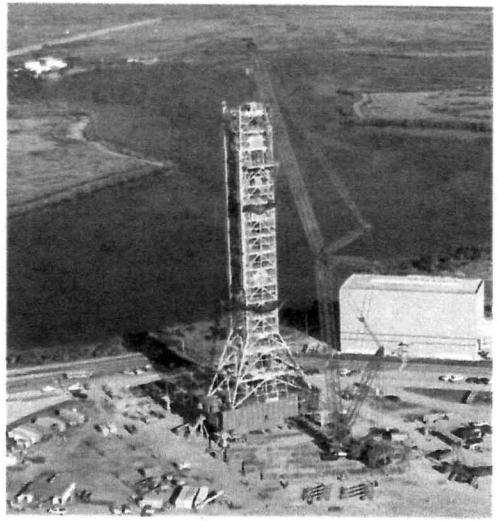
- **USA/Hangar N NDE Primary Services**
  - **Provide Non-Destructive Testing and Evaluation for the Space Shuttle and other KSC Operational Programs**
    - Performs inspections in support of space operations and maintenance of multi-purpose space systems
    - Provides NDE Project Engineering for New Technology Development
    - Includes advanced NDE capabilities
      - Flash Infrared Thermography (Orbiter Wing Leading Edge)
      - Terahertz (External Tank)
      - Backscatter x-ray (External Tank)
  - **Provide R&D collaboration with the NASA Engineering Safety Center (NESC) NDE Technical Development Team**

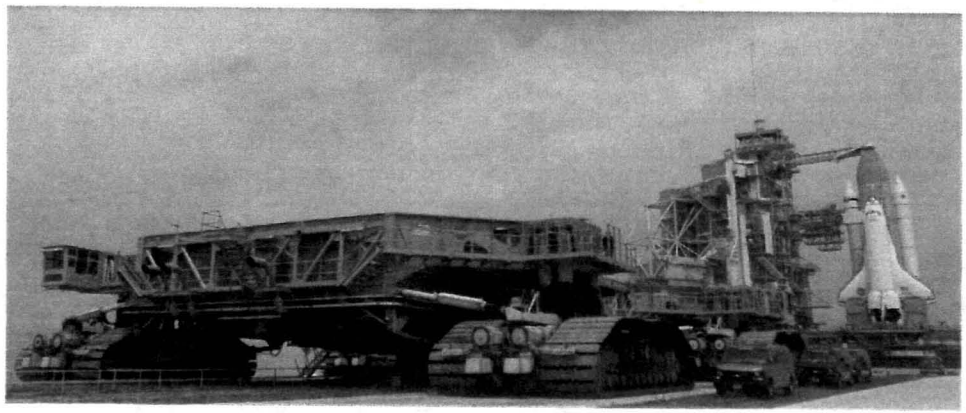
Some cross linking exists amongst the 2 laboratories – Consolidation plans are currently being discussed

Institutional (ISC) Non-Destructive Examination Laboratory

- **Skills and Capabilities**
  - Eddy Current Testing
  - Infrared imaging
  - Leak Testing
  - Micro-Focus X-Ray
  - Magnetic Particle
  - Fluorescent Dye Penetrant
  - Radiography
    - High Energy X-Ray – 420 kV
    - Portable X-Ray and Gamma Sources
    - Computed Tomography (CT)
  - Ultrasonic Testing
  - Visual
    - Certified Weld Inspection (CWI)
  - ASNT-certified Level III engineering consulting

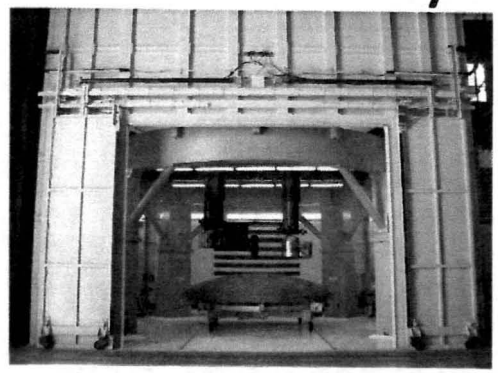


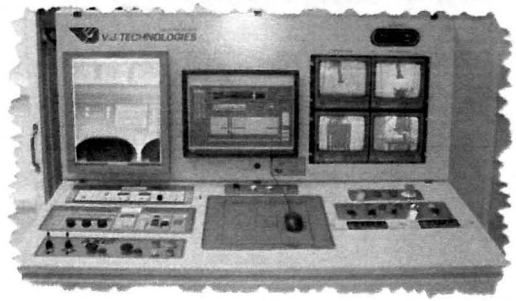


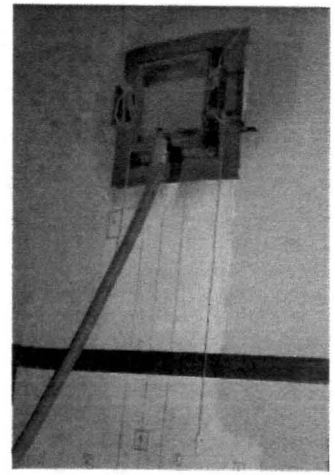


USA/Hangar N Non-Destructive Examination Laboratory

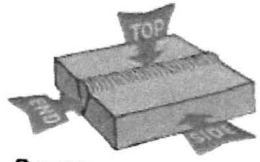
- **Skills and Capabilities**
  - Radiography
    - CT
    - Film and Digital
    - Laminography
  - Ultrasonic
    - A-Scan, B-Scan, P-Scan
    - 3D CAD UT Modeling
  - Flash Thermography imaging
  - Shearography – Vacuum/Acoustic
  - Magnetic Particle
  - Fluorescent Dye Penetrant
  - Visual
    - CWI, Dimensional, UV Borescope
  - Eddy Current
    - MWM, Single/Multi Channel
    - Bolt Hole/Surface
    - Custom Coil
  - Terahertz
  - Large scale X-Ray Chamber
    - 11-Axis Robot and gantry
  - Structural Health Monitoring (IVHM)



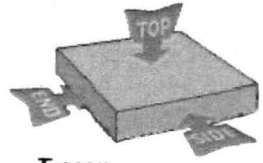




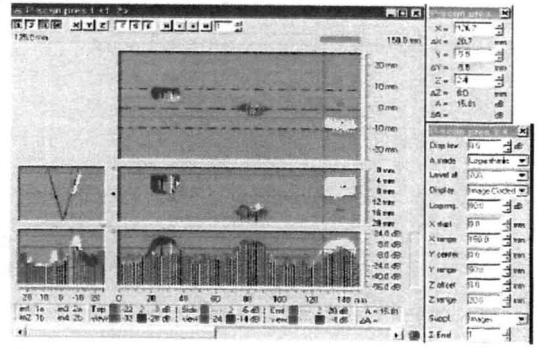
Shuttle External Tank Foam Shearography Inspection



P-scan



T-scan

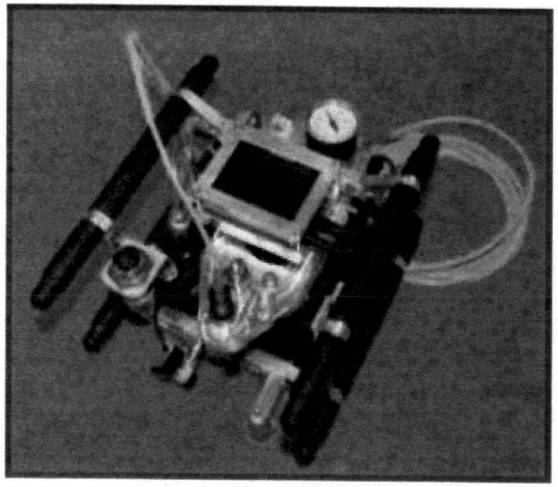


P-scan presentation

Materials Science Division Support

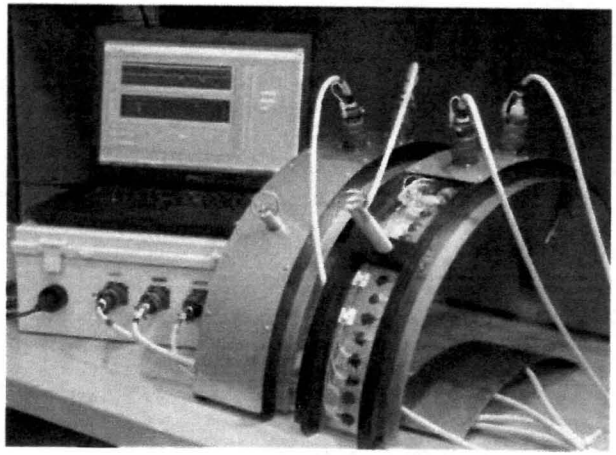
- Materials & Processes Engineering
  - Program support (engineering/project management)
  - ESD Composites for Exploration
  - OCT Composites Cryotank
  - R&D
- Applied Physics Lab
  - Program support (applied R&D)
  - R&D
- NASA NDE Working Group (NNWG)
- NESC NDE TDT

Example of Past Projects



Device for making detailed maps of orbiter window defects

Ultrasonic leak locator



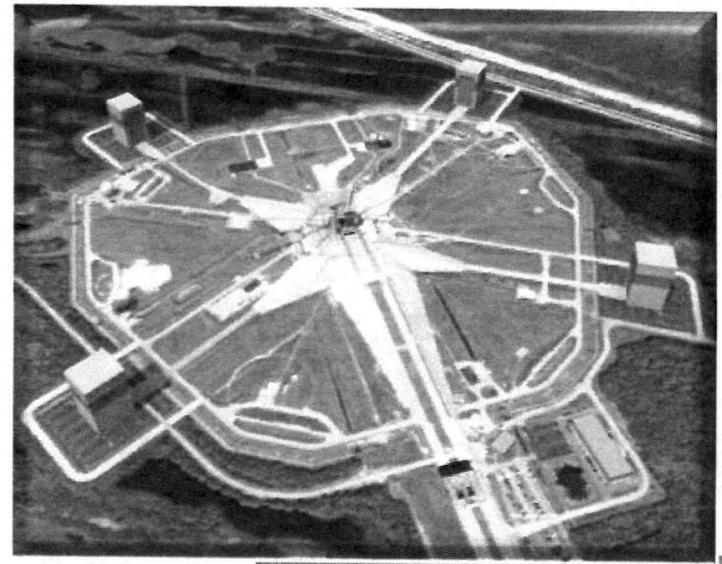
Prototype device to indicate H2 leakage or fire at a flanged joint.

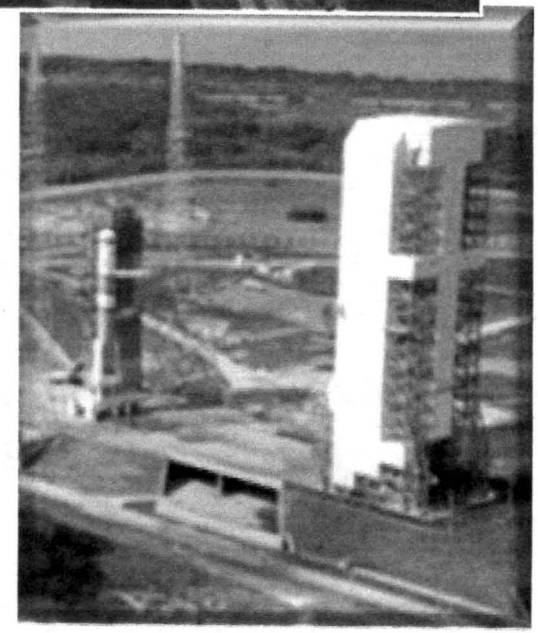
Current/Future NDE Customers

- KSC/CCAFS Institution
  - e.g. Pad modifications, cyrotanks, crawler transporter, pressure vessels
- Launch Services Program (LSP)
- 21st Century Launch Program
  - Orion MPCV
  - SLS
- Commercial Cargo
- Commercial Crew

21st Century Launch Complex

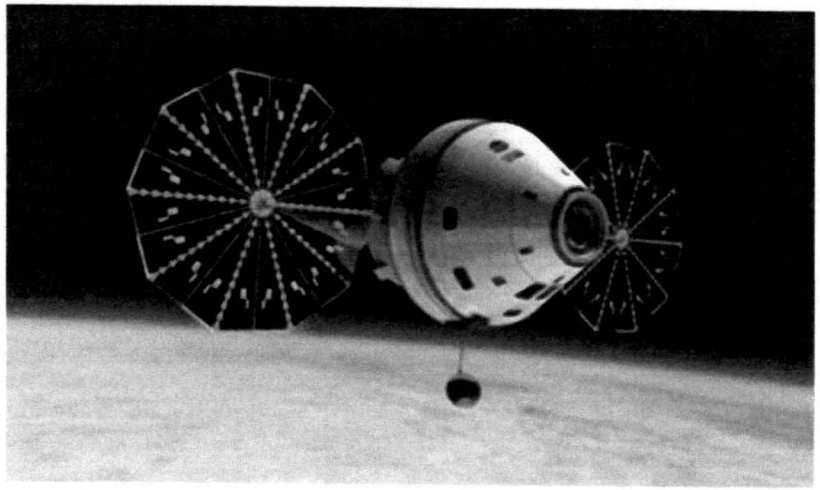
- Modernizing the KSC and CCFAS
  - Launch architecture
  - Environmental
  - Payload Processing
  - Range Capabilities
  - Partnering with Air Force, State of Florida and the FAA

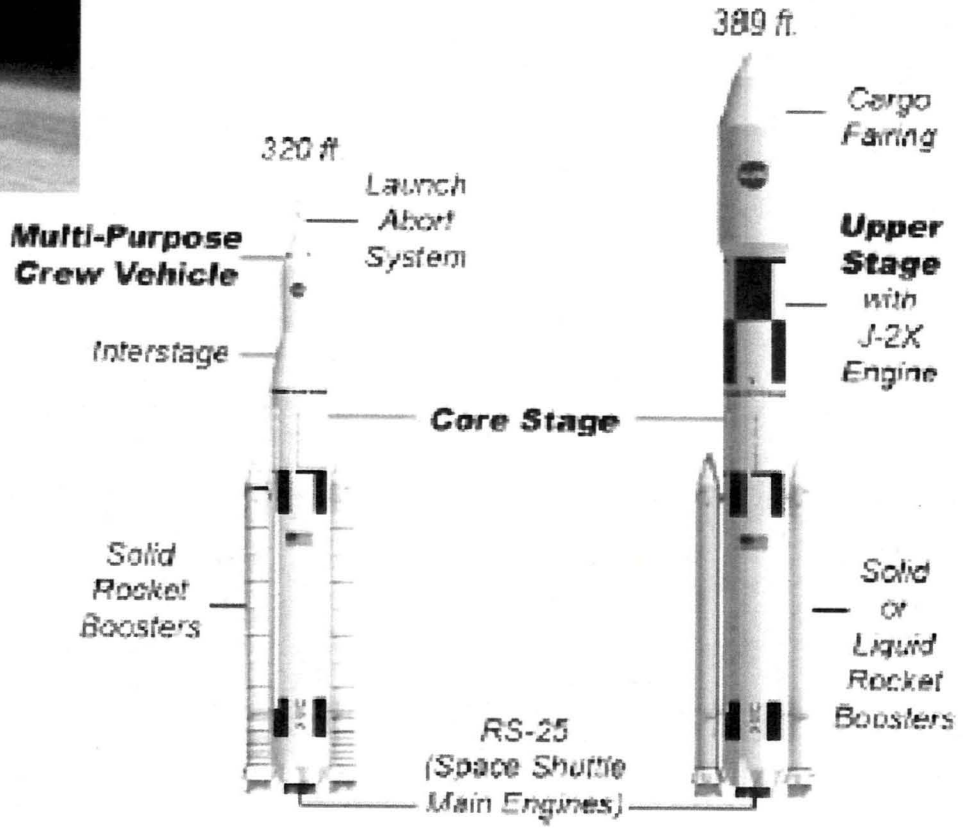




KSC ENGINEERING AND TECHNOLOGY

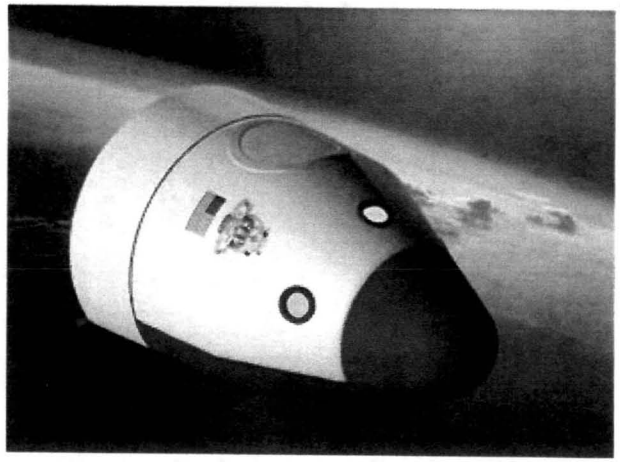
Orion MPCV and SLS





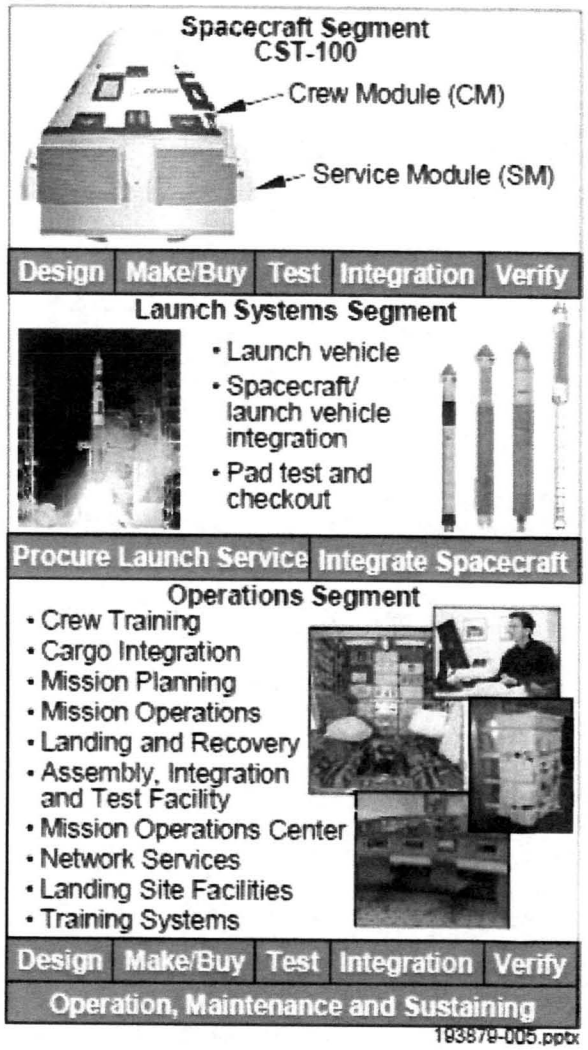
Commercial Crew - Blue Origin

- Developing a Crew Transportation System comprised of a Space Vehicle (SV) which will be launched first on an Atlas V and then on Blue Origin's own Reusable Booster System (RBS)
- Capable of carrying 7 astronauts and will transfer NASA crew and cargo to and from the ISS, serve as an ISS emergency escape vehicle for up to210 days, and perform a land landing to minimize the costs of recovery and reuse.



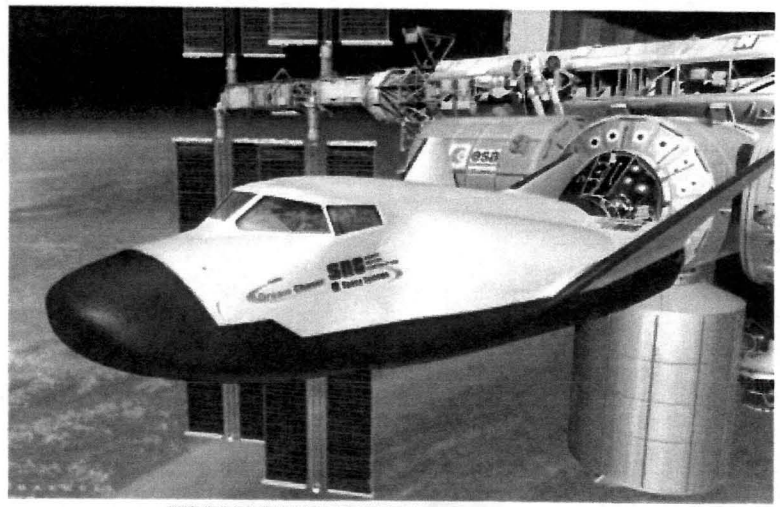
Commercial Crew - Boeing

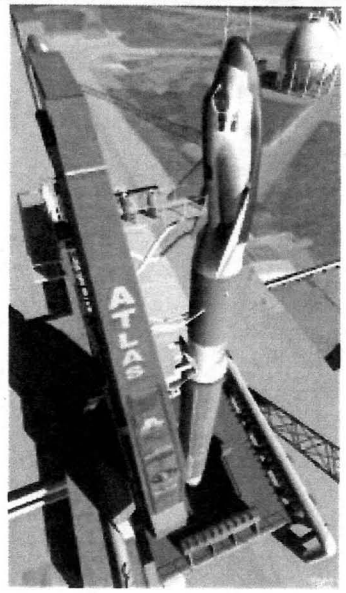
- Developing a "full service" system for both NASA and commercial customers to LEO destinations.
- CST-100 spacecraft is configured to carry up to 7 crew members and/or cargo to LEO destinations including ISS and BA Sundancer space complex
- Compatible with multiple launch vehicles
- Designed for land landings and can be reused for up to 10 missions



Commercial Crew - Sierra Nevada

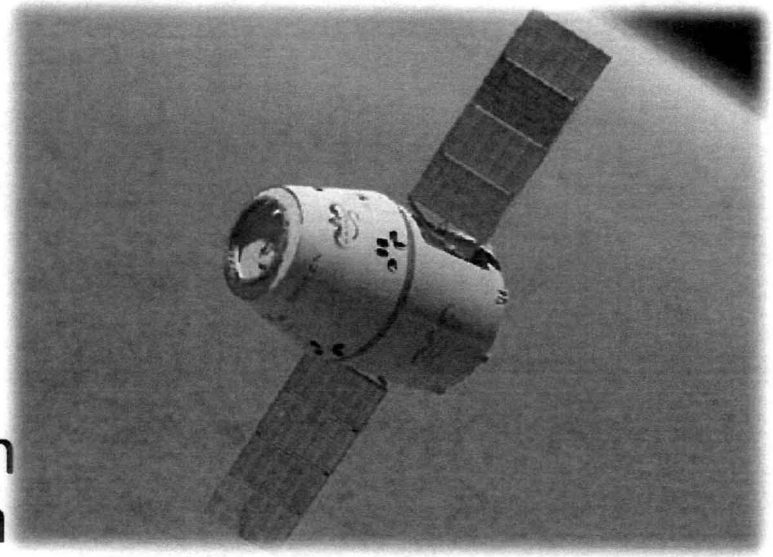
- Developing the Dream Chaser Space System (DCSS).
- Provides LEO access to the ISS and commercial customers needing suborbital services
- Third generation design derived from extensive NASA Langley research providing a reusable, pressurized, lifting-body vehicle that lands on a conventional runway.
- Will most likely utilize an Atlas V launch vehicle

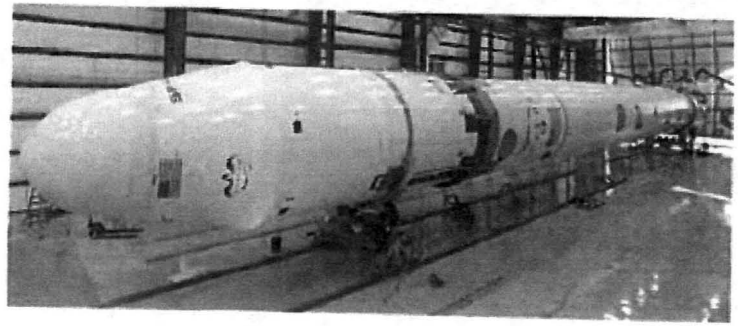




Commercial Crew - SpaceX

- SpaceX's Dragon crew vehicle was the first commercial spacecraft to return from orbit
- Maturation of the Falcon9/Dragon transportation system with a particular focus on developing an integrated Launch Abort System.
- Developing prototypes of the crew cabin, crew seats and restraints, crew control panel and life support system.



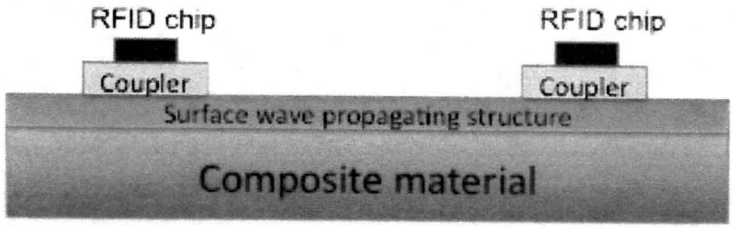


So what are KSC's needs?

- The basic infrastructure of NDE support will remain but at a reduced capacity, especially in advanced NDE development
  - Consolidation is still in work
- The new NASA programs and the new commercial customers do not have the "deep pockets" that the Shuttle Program had
  - The challenge for KSC is to maintain a world class NDE organization with less resources
- The NASA Materials Science Division will remain the POC for NDE operations and advance NDE development
  - Key challenge is to forecast future customer needs
  - Examples of a few recent development efforts are on the following charts

Multifunctional Hybrid Composite Metamaterial Systems

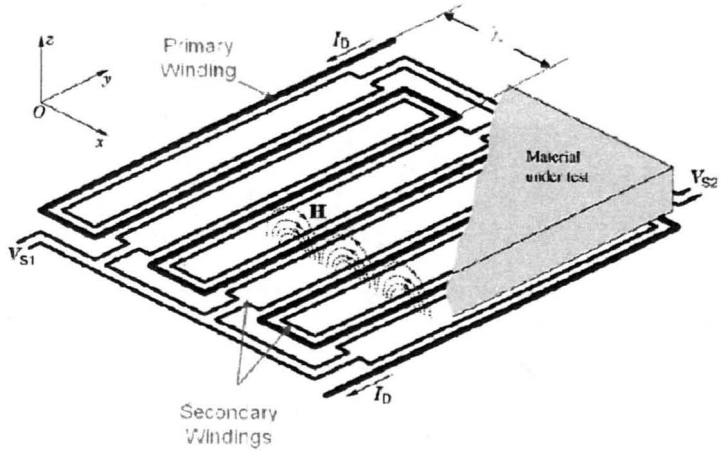
- Inspection of damage and subsequent repairs on composite structures which will involve:
  - Develop a Surface Wave propagating (SWP) structure consisting of arrayed sensors (piezoelectric), in conjunction with a passive single chip Radiofrequency Identification (RFID) strain/accelerometer/temp sensor configuration.
    - The goal will be to simultaneously transfer power, and communicate via a wireless network, in order to detect damage and induce or monitor the cure of a repair in a fiber reinforced composite part.
    - Validation of the tools using current NDI/NDE methods
- Repair of materials for primary structures (including newly developed out of autoclave material designed for use on primary structures).
  - Cradle-to-grave monitoring of the repair including monitoring repair cure, the initial quality of repair during installation and continuing the monitoring throughout its lifetime.
  - Provide cost-cutting measures for repair of out-of-autoclave composite structures for primary structures through the development of standard repair and monitoring kits

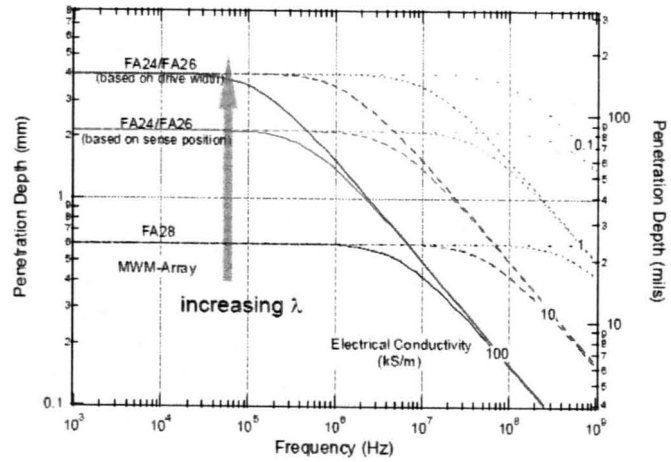


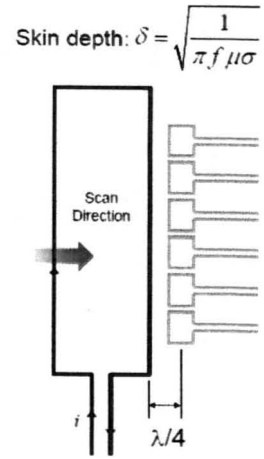
Cross-section view

Eddy Current Stress Gages for COPV Health Monitoring

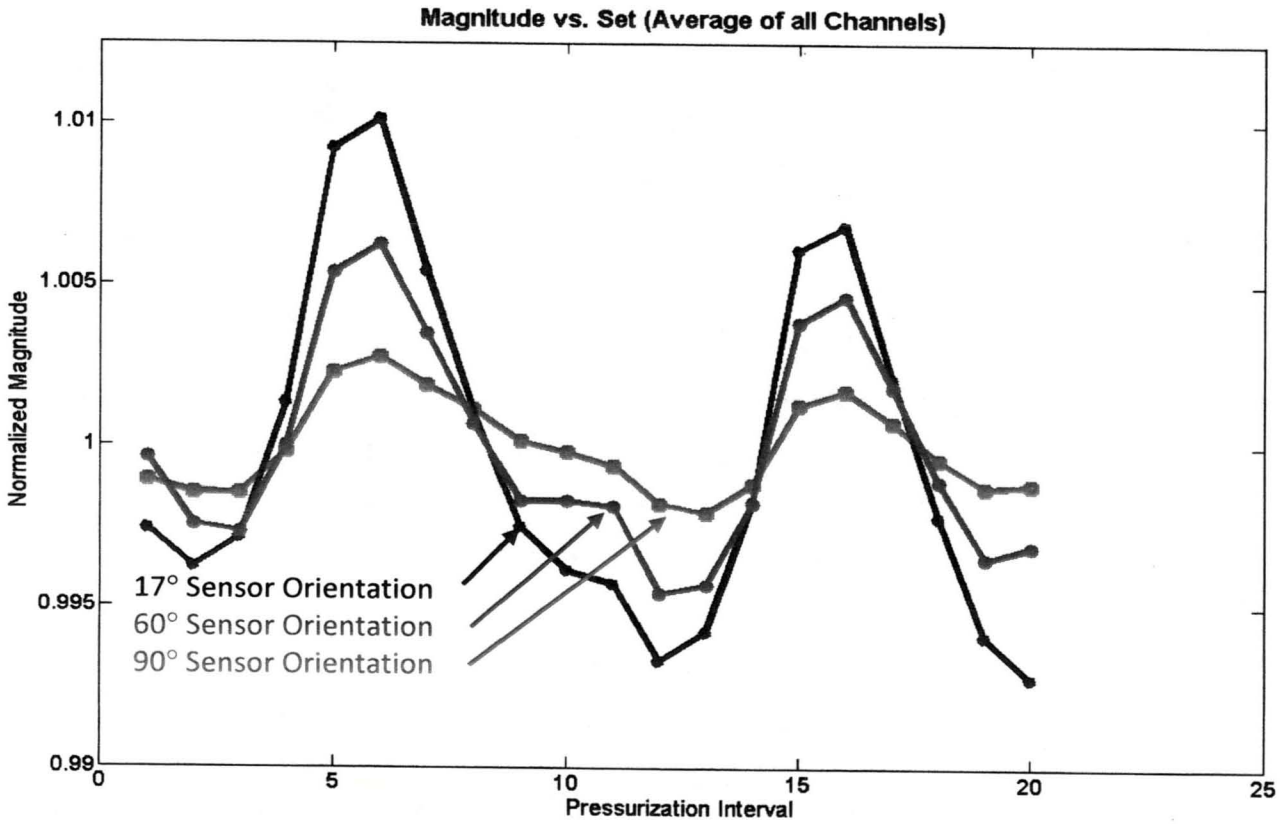
- Utilizes MWM® Technology
  - Goal is to provide a means of directly measuring the stresses at various depths in the overwrap

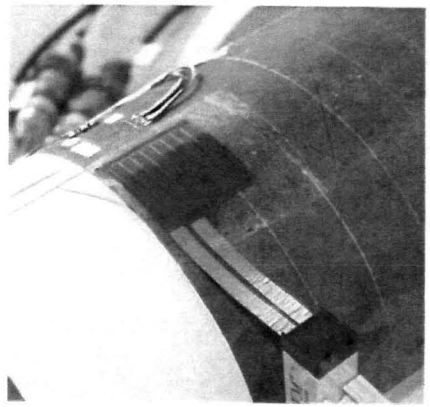


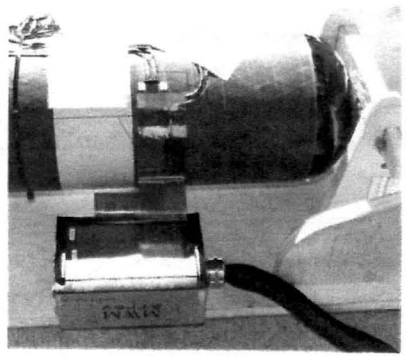




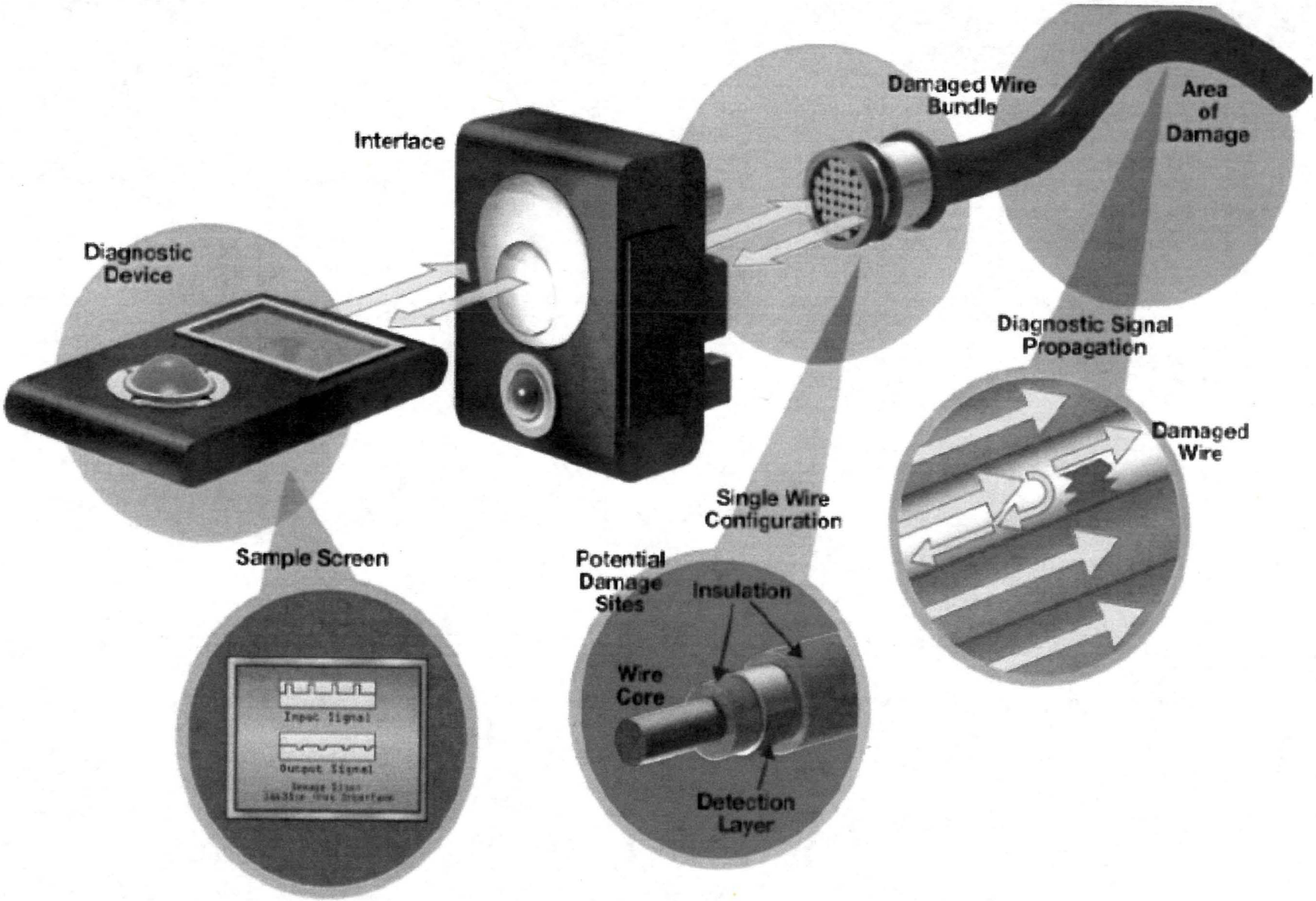
Eddy Current Stress Gages for COPV Health Monitoring







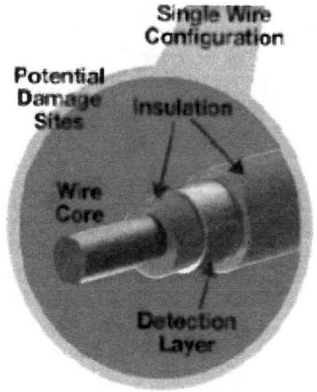
Wire Detection Systems & Integration

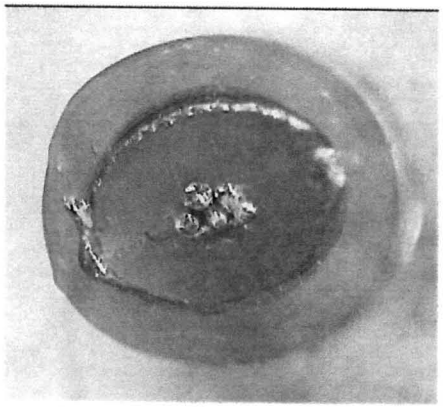


Wire Construction

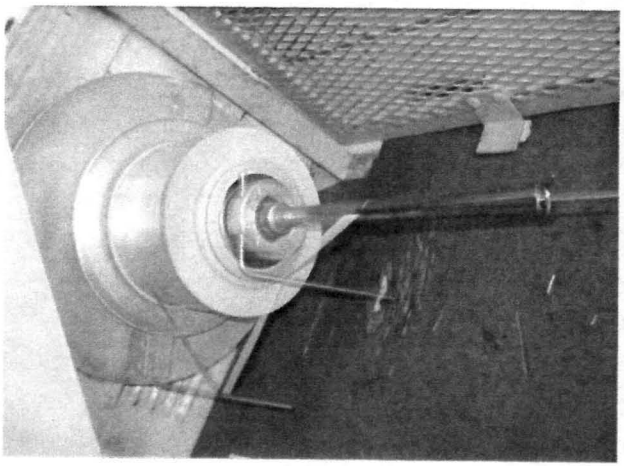
Materials examined during development of detection layer

- Metal foils
- Nickel coated carbon fiber
- Conductive carbon cloth
- Metallized mylar tapes
- Sputter coated metals
- Electroplated metals
- Printed-on conductive inks
- Inherently conductive polymers

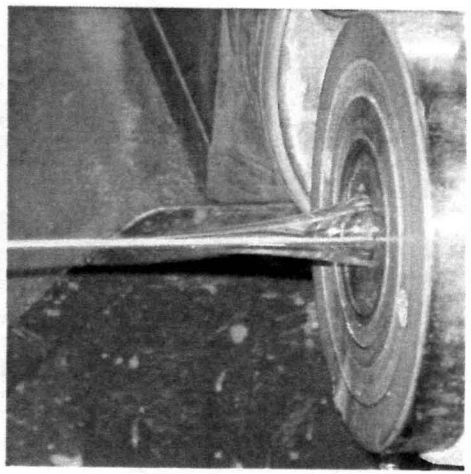




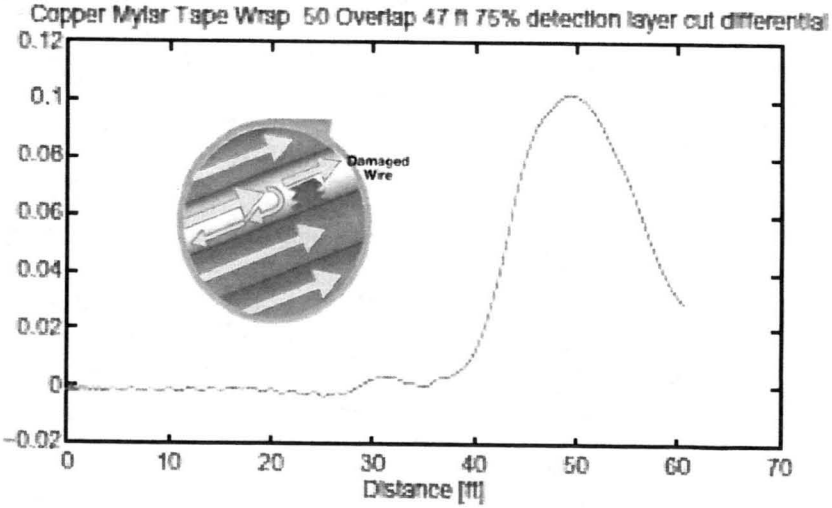
Cross section of RG316 wire with Cu foil and PTFE jacket



Tape wrapped



Extruded FEP



Damage profile for TDR testing